Volcanoes

Chapter 5

Rigid Earth to Plate Tectonics

- **Learning Objectives**
  - **Know the different types of volcanoes and their associated features**
  - **Understand the relationship of the volcanoes to plate tectonics**
  - **Know what geographic regions are at risk from volcanoes**
  - **Know the effects of volcanoes and how they are linked to other natural hazards**
  - **Recognize the potential benefits of volcanic eruptions**
  - **Understand how we can minimize the volcanic hazard**
  - **Know what the adjustments we can make to avoid death and damage from volcanoes**

Introduction to Volcanoes

- **General term that refers to all phenomena connected with the origin and movement of molten rock**
  - **Two categories–Surface and Plutonic Activities** (below the surface of the crust)
    - **Extrusive volcanism (explosive above ground)**
    - **Intrusive volcanism (shallow none explosive)**
      - **Plutonic (intrusive, very deep under ground)**

Magma

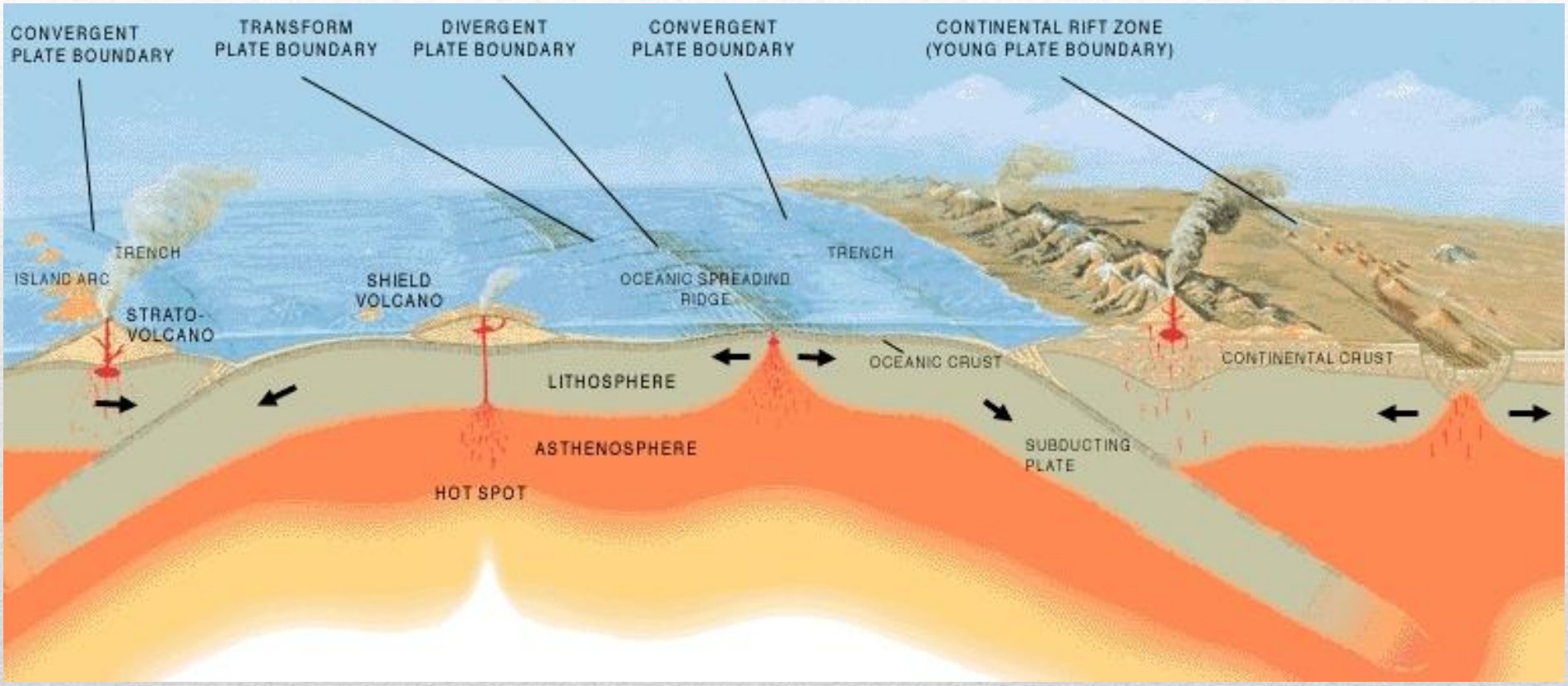
- **Magma**
  - **Molten mineral material below the surface** –
  - **Lava when extruded to the surface**.
  - **Explosive material is pyroclastic material**
  - **Distribution**—Most found in the Ring of Fire or at subduction zones

- **Magma Chemistry and style of eruptions**
  - **Felsic Magma** – Rhyolite and Granite
    - Explosive eruptions

    Mafic Magma – Basalt and Gabbro
    - Slow moving, non-explosive

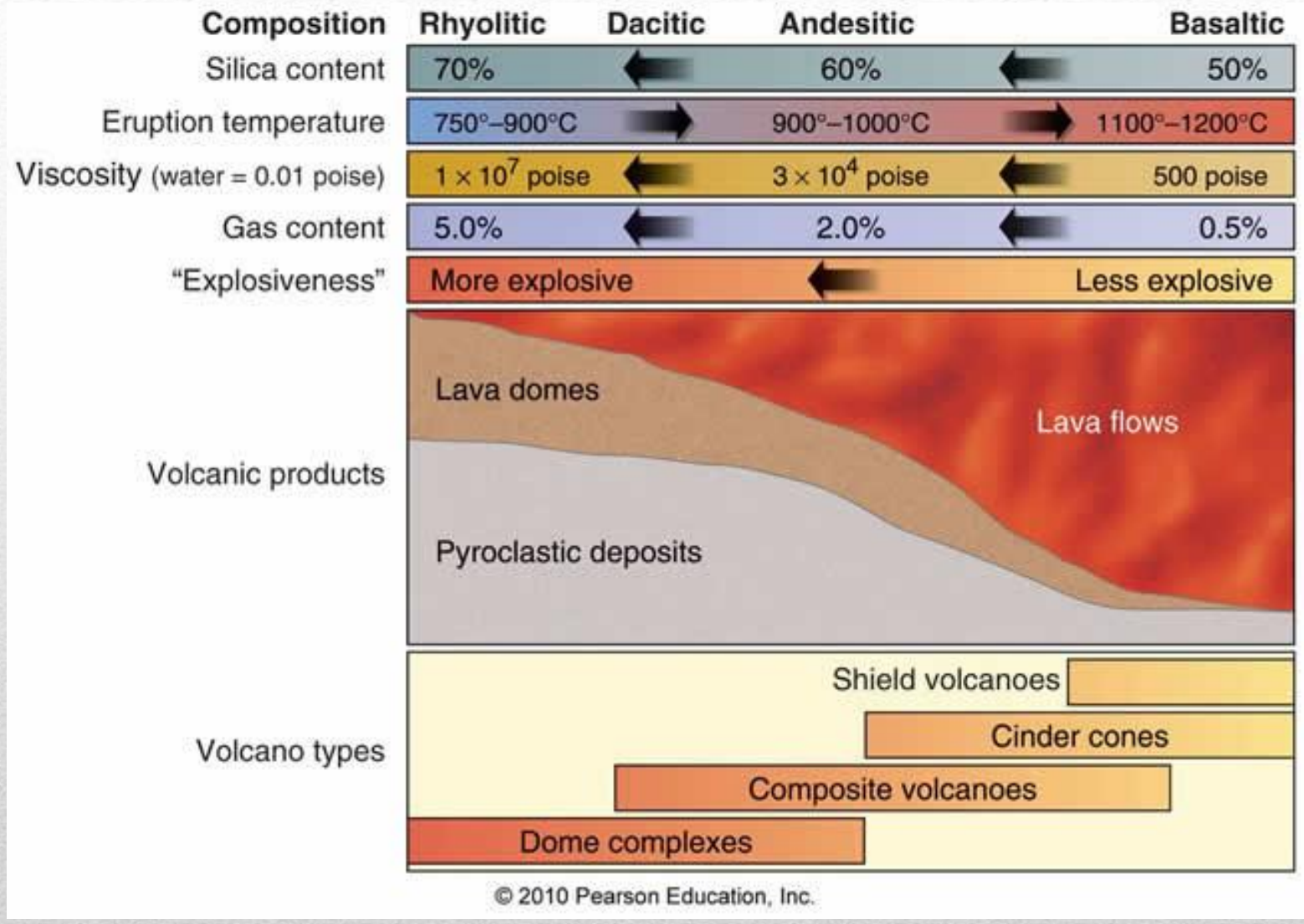
How Magma Forms

- Decompression melting – when overlying pressure is exerted on hot rock within the asthenosphere is decreased.
  - Happens at Hot Spots and Divergent boundaries
- Addition of volatiles lowers the melting temperature of rocks by helping to break chemical bonds within silicate minerals
  - Volatiles are chemical compounds, such as such as water or carbon dioxide that evaporate and exist in a gaseous state at the earth's surface
- Addition of heat to rocks will induce melting if the temperature of the rocks exceeds the melting temperature of silicate rocks at that depth


CONVERGENT PLATE BOUNDARY
TRANSFORM PLATE BOUNDARY
DIVERGENT PLATE BOUNDARY
CONVERGENT PLATE BOUNDARY
CONTINENTAL RIFT ZONE (YOUNG PLATE BOUNDARY)
TRENCH
ISLAND ARC
STRATO-VOLCANO
SHIELD VOLCANO
OCEANIC SPREADING RIDGE
TRENCH
OCEANIC CRUST
CONTINENTAL CRUST
LITHOSPHERE
ASTHENOSPHERE
SUBDUCTING PLATE
HOT SPOT

Properties of Magma

- Magma is made up of melted silicate rocks
  - Basaltic, Andesitic, and Rhyolitic
  - Magma is less dense than surrounding rock therefore it rises buoyantly towards the surface
  - As it moves towards the surface and melting takes place, chemical processes happen and magma becomes more felsic
- Viscosity is the resistance to flow due to greater amounts of silica in the magma
  - The viscosity of the magma influences the type of volcano
- Volatile Content of the volcano is connected to a high concentration of dissolved volatiles within the magma


Composition
Rhyolitic
Dacitic
Andesitic
Basaltic
Silica content
70%
60%
50%
Eruption temperature
750°–900°C
900°–1000°C
1100°–1200°C
Viscosity (water = 0.01 poise)
1 × 10^7 poise
3 × 10^4 poise
500 poise
Gas content
5.0%
2.0%
0.5%
"Explosiveness"
More explosive
Less explosive
Volcanic products
Lava domes
Lava flows
Pyroclastic deposits
Volcano types
Shield volcanoes
Cinder cones
Composite volcanoes
Dome complexes
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Types of Volcanoes

- **Shield**
  - Broad, gentle slope
  - Largest in the world
  - Layers of lava flows
  - Basaltic magma, quiet eruptions
  - Common in islands, Hawaii and Iceland
- **Composite**
  - Large, steep, symmetrical
  - Beautiful cone shape
  - Layers of lava, proclastic
  - Magma andesitic, both explosive and quiet eruptions
  - Mt. Fuju, Mt. St. Helen, Mt. Rainier

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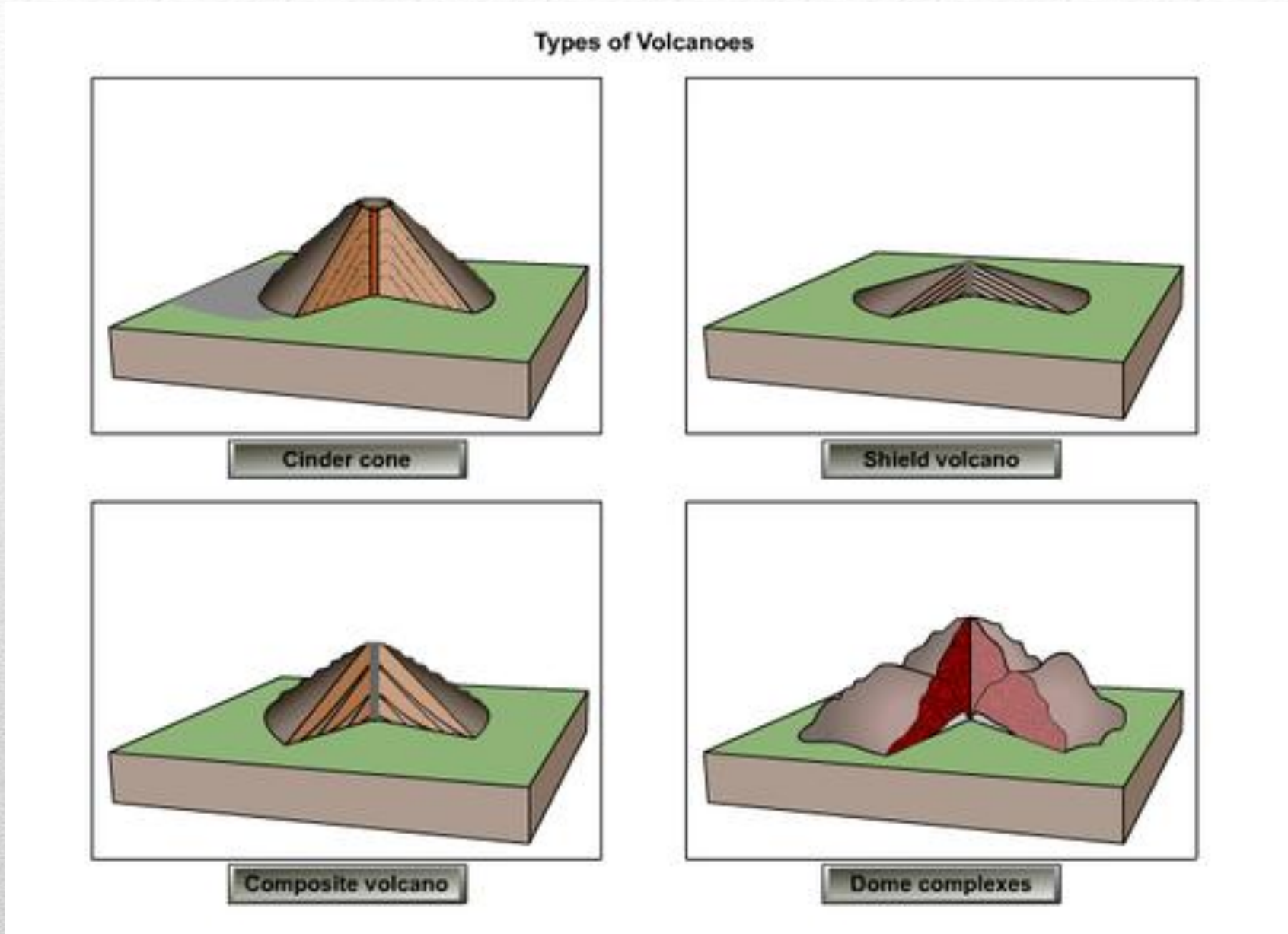
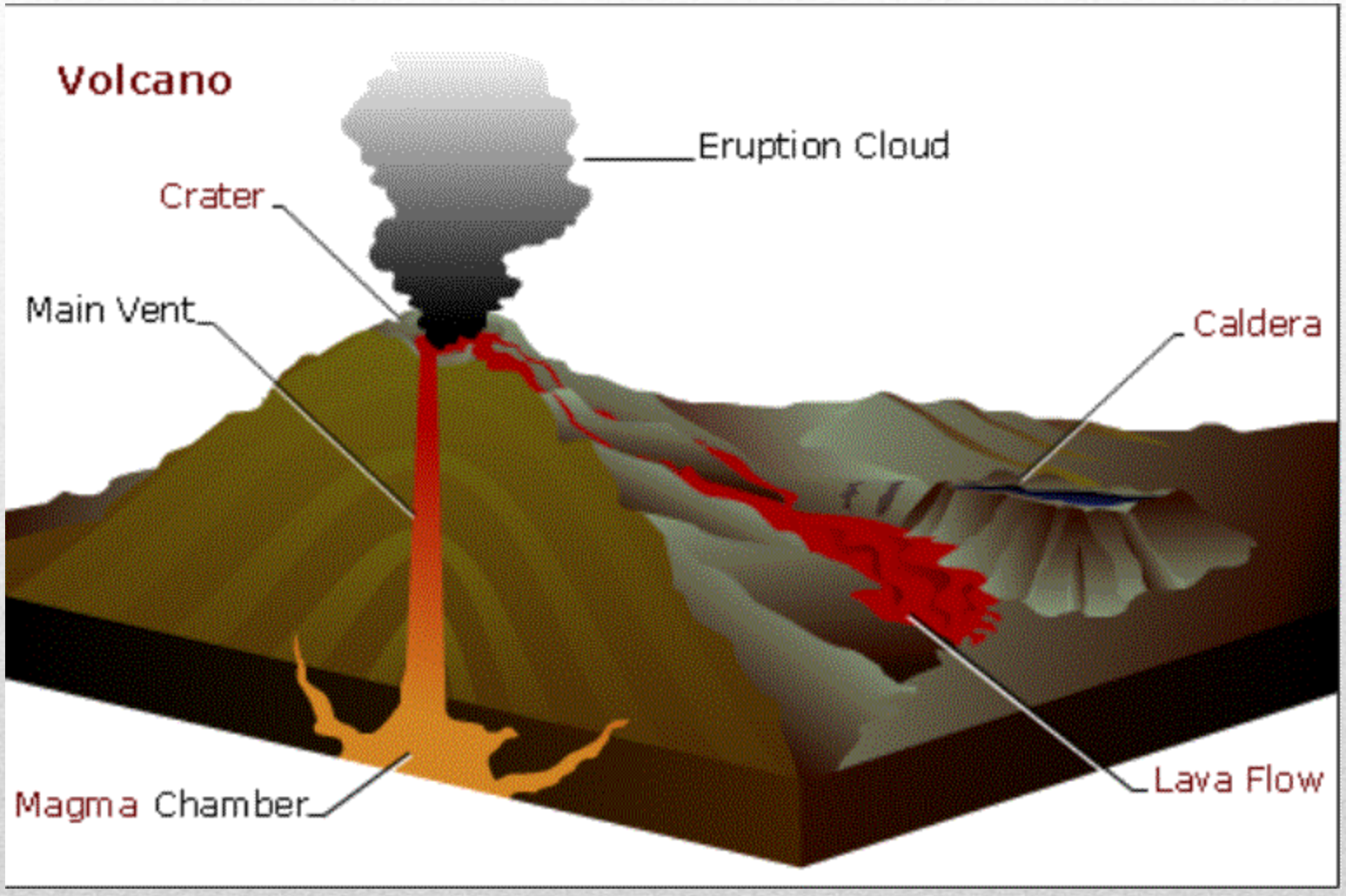
Types of Volcanoes

- **Lave Dome**
  - Small, less than 2000 ft. high, irregular shape
  - Solidified thick viscous lava
  - Magma high in silica, often rhyolite
- **Cinder Cone**
  - Small Steep-sided.
  - Loose proclastic material
  - Magma varies from basaltic to proclastic


Types of Volcanoes
Cinder cone
Shield volcano
Composite volcano
Dome complexes

Parts of Volcanoes

- Volcanoes are more than complex systems in a mountain that spews lava
  - These systems include:
    - Craters, calderas, volcanic vents, geysers, and hot springs
      - **Craters** – formed at the topes of volcanoes during the explosion
      - **Volcanic vent --** an opening through with lava and pyroclastic erupts
      - **Hot Springs or geysers** – where groundwater comes into contact with hot rock
      - **Caldera --**a crater produced from a collapsed volcano


Volcano
Eruption Cloud
Crater
Main Vent
Caldera
Lava Flow
Magma Chamber

How a Caldera is formed

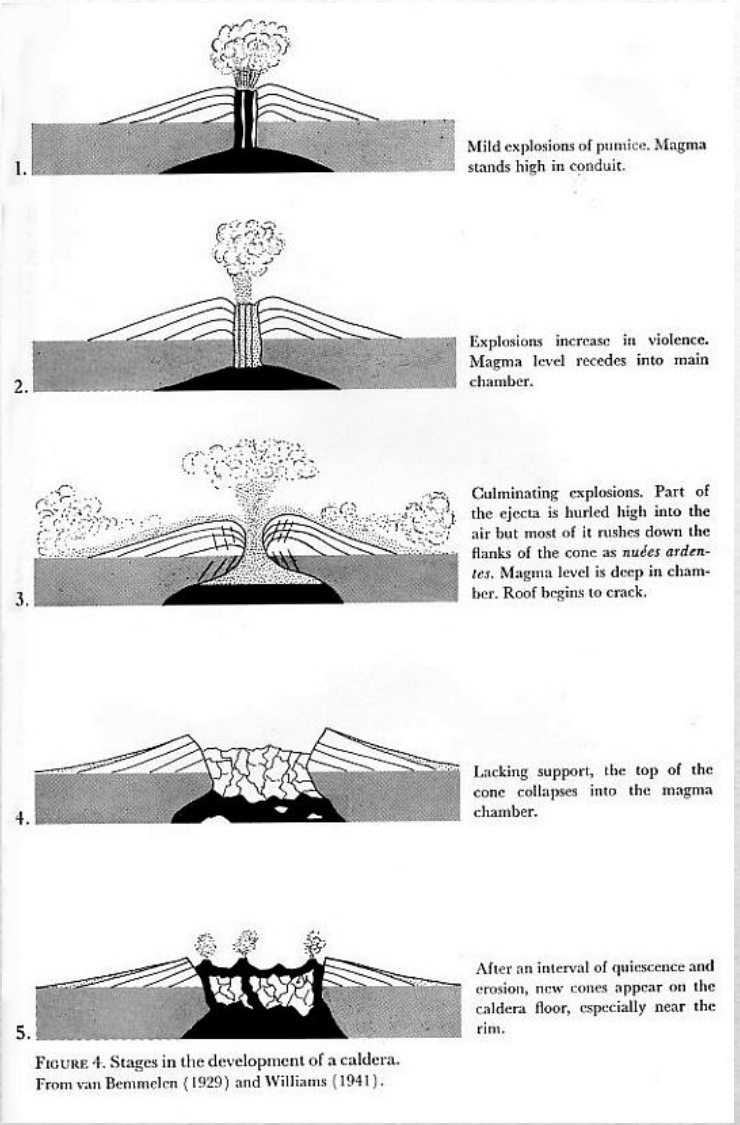
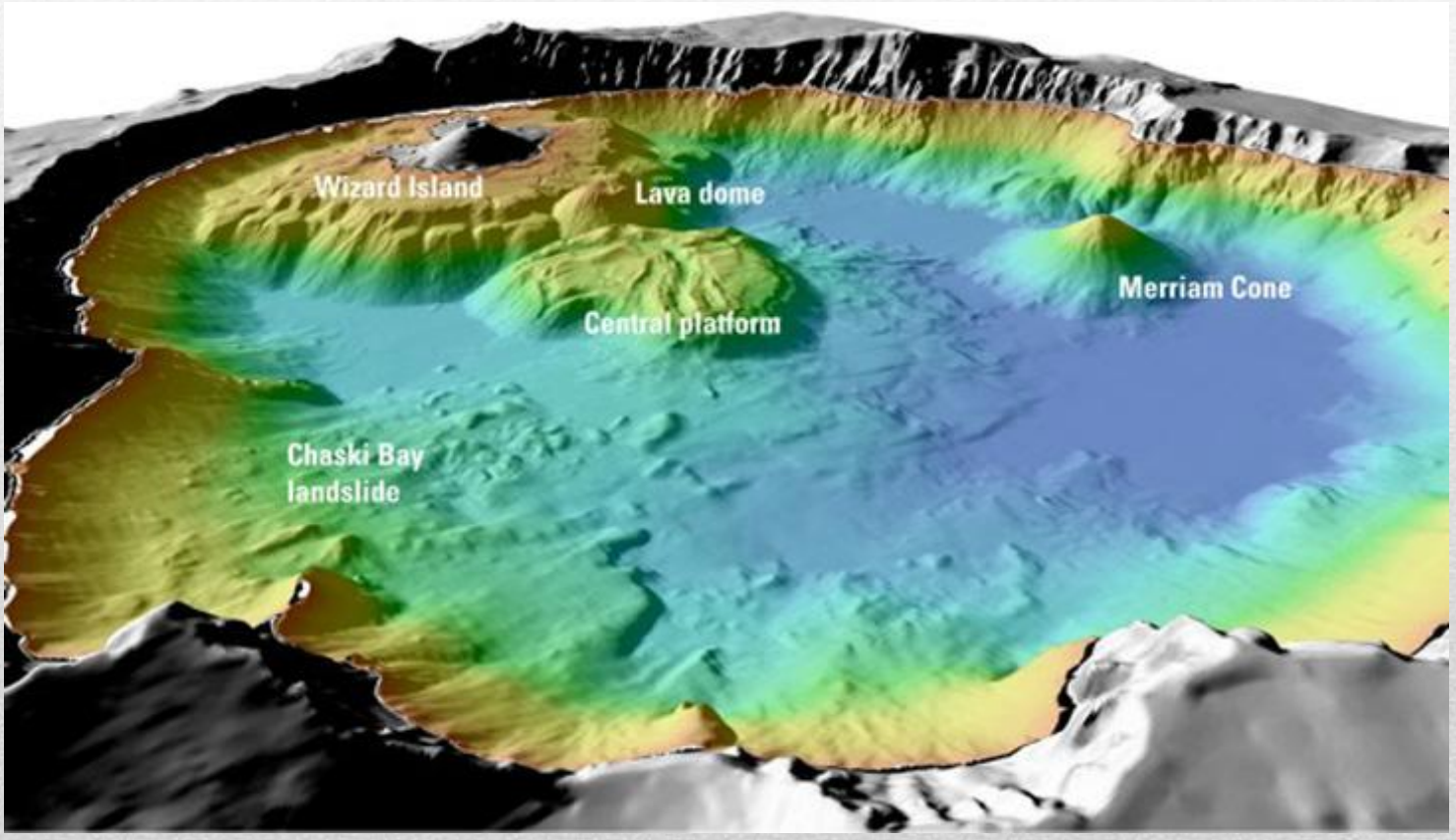


FIGURE 4. Stages in the development of a caldera.
From van Bemmelen (1929) and Williams (1941).

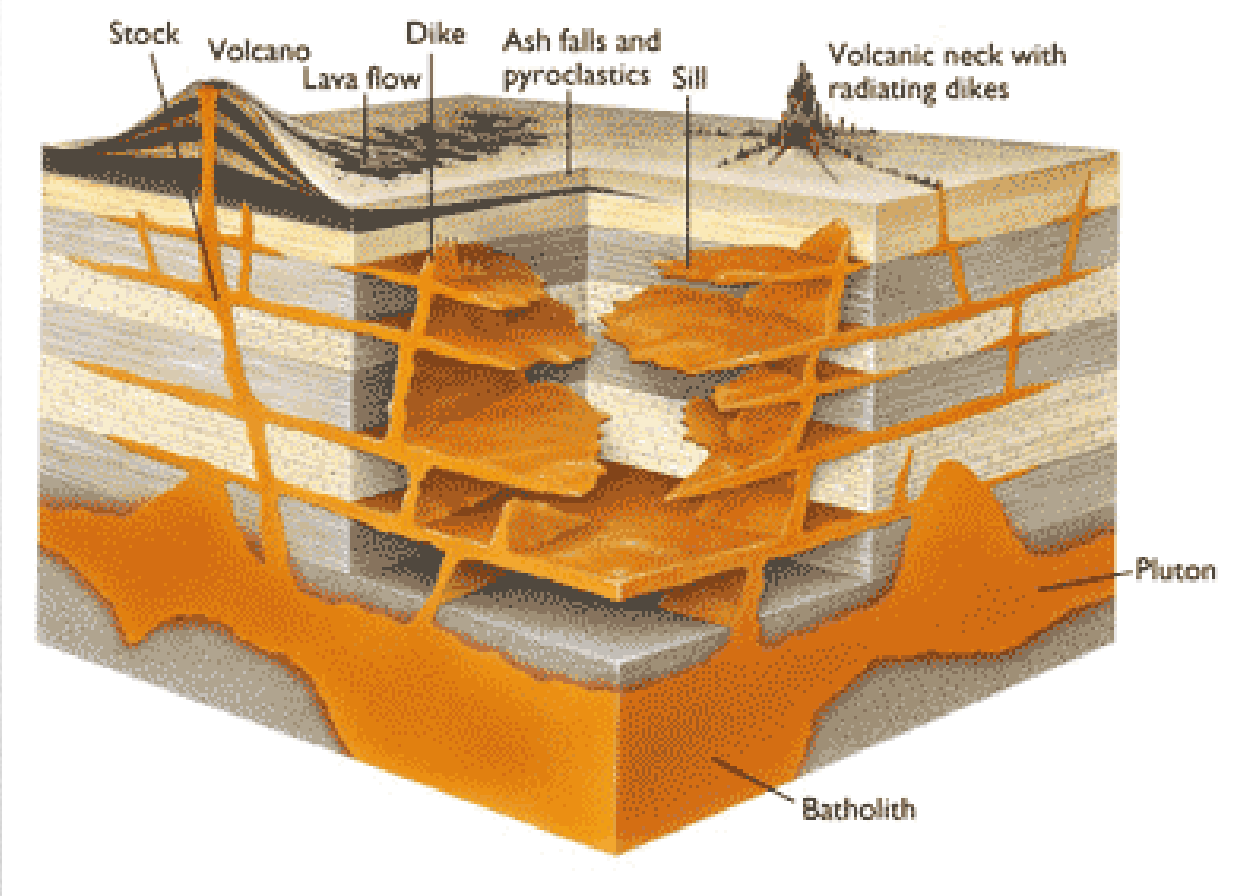
Types of Volcanoes

Crater Lake -- Caldera



Igneous Features

- **Igneous intrusions – when the magma solidifies below the surface producing a igneous intrusion**
  - **Dikes – a vertical or nearly vertical sheet of magma thrust upward into preexisting rock**
  - **Sills– a long, thin intrusive body with its orientation determined by the structure of the preexisting rocks.**
  - **Veins – least prominent- thin veins of igneous rock that are pushed up through small fractures of preexisting rocks.**
  - **Batholiths -- a subterranean igneous body of indefinite depth and enormous in size. Often the core of mountain ranges.**
  - **Stocks – Similar to the batholiths but much smaller. Often an offshoot of batholiths.**
  - **Laccoliths– produces by slow-flowing viscous magma is forced between horizontal layers of preexisting rock.**


Stock
Volcano
Lava flow
Dike
Ash falls and pyroclastics
Sill
Volcanic neck with radiating dikes
Pluton
Batholith

Mid-ocean Ridges and Continental Rifts Volcanoes

- Mid-ocean ridges and continental rifts
  - Produces basaltic magma
  - Produces shield volcanoes
  - Iceland an example

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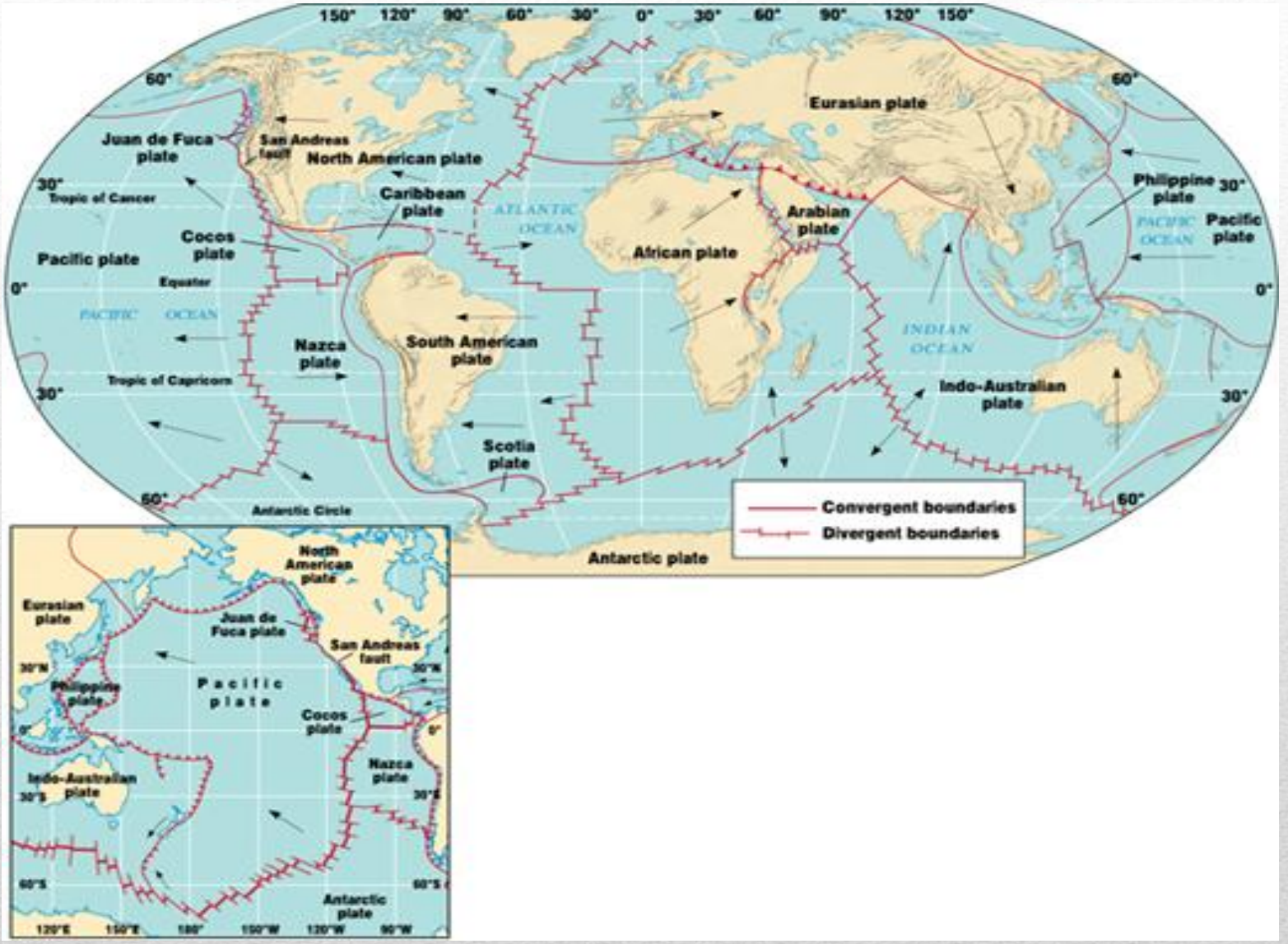
150° 120° 90° 60° 30° 0° 30° 60° 90° 120° 150°
60°
30°
0°
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic Circle
Juan de Fuca plate
San Andreas fault
North American plate
Caribbean plate
Cocos plate
Pacific plate
Nazca plate
South American plate
Scotia plate
Antarctic plate
Eurasian plate
African plate
Arabian plate
Philippine plate
Pacific plate
Indo-Australian plate
ATLANTIC OCEAN
PACIFIC OCEAN
INDIAN OCEAN
Convergent boundaries
Divergent boundaries
North American plate
Eurasian plate
Juan de Fuca plate
San Andreas fault
Philippine plate
Pacific plate
Cocos plate
Nazca plate
Indo-Australian plate
Antarctic plate
30°N
30°S
60°S
120°E
150°E
180°
150°W
120°W
90°W

Subduction Zone Volcanoes

- Subduction Zones
  - Found around the Pacific Rim
  - Volcanoes commonly andesitic
  - Magma combination of basalt and silica
  - Japan and volcanoes in Oregon, Washington and Alaska are examples

Convergent Boundaries

- Convergent Boundaries– where plates collide destructive boundaries
  - Most massive and spectacular of earthly landforms
    - Mountains & volcanoes
    - Deep ocean trenches

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Koyukuk terrane
ALASKA
Aleutian Trench
Wrangellia terrane
PACIFIC PLATE
CANADA
Alexander terrane
JUAN DE FUCA PLATE
Cascadia Trench
NORTH AMERICAN PLATE
Sonoma terrane
SAN ANDREAS FAULT
UNITED STATES
Salton Trough
Guerrero terrane
MEXICO
East Pacific Rise
EXPLANATION
Island arc
Submarine deposits
Ancient ocean floor
Attached fragments
Ancient continental interior (craton)
Divergent boundary
Convergent boundary
Transform boundary

Hot Spots

- **Hot Spots**
  - Spots of volcanic activity caused by a thin Earth's crust allowing the magma to move to the surface found in the ocean
  - These are called **Hot Spots**
    - **Hawaii** is an example
    - As the plate moves across the Hot Spot, a **hot spot trail is left, such as the Hawaiian Islands or Midway**.

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Mantle Plums

- **Mantle Plumes**
  - Spots of volcanic activity caused by a thin Earth's crust allowing the magma to move to the surface
    - These are called **Mantle Plumes**
    - Yellowstone sits over a mantle plume
  - As the North American plate moves across this mantle plum**,** Yellowstone will move across the country
  - **Mantle plumes help to explain volcanic activity in the middle of plates and help to distinguish the direction of the plate's movement.**

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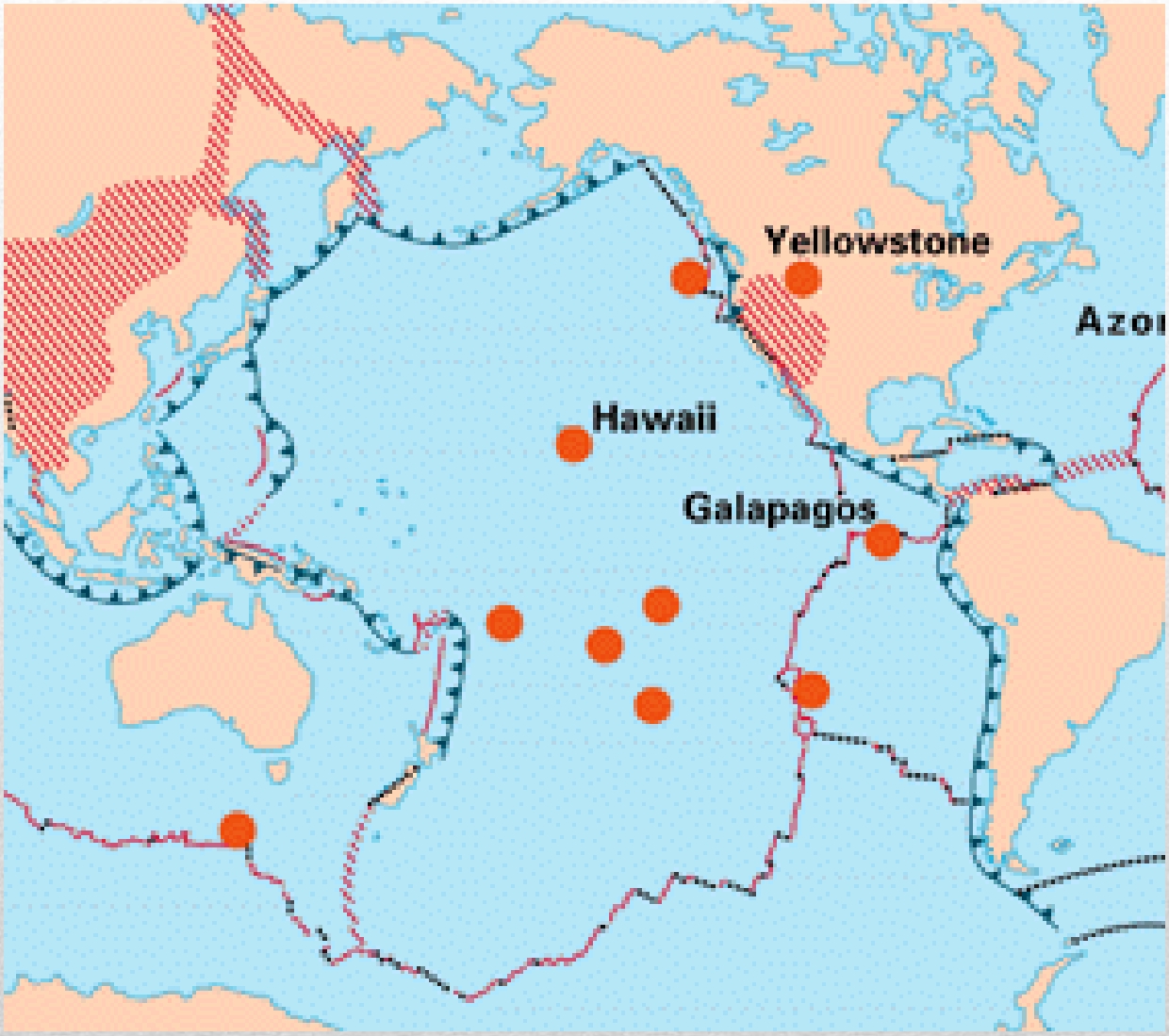
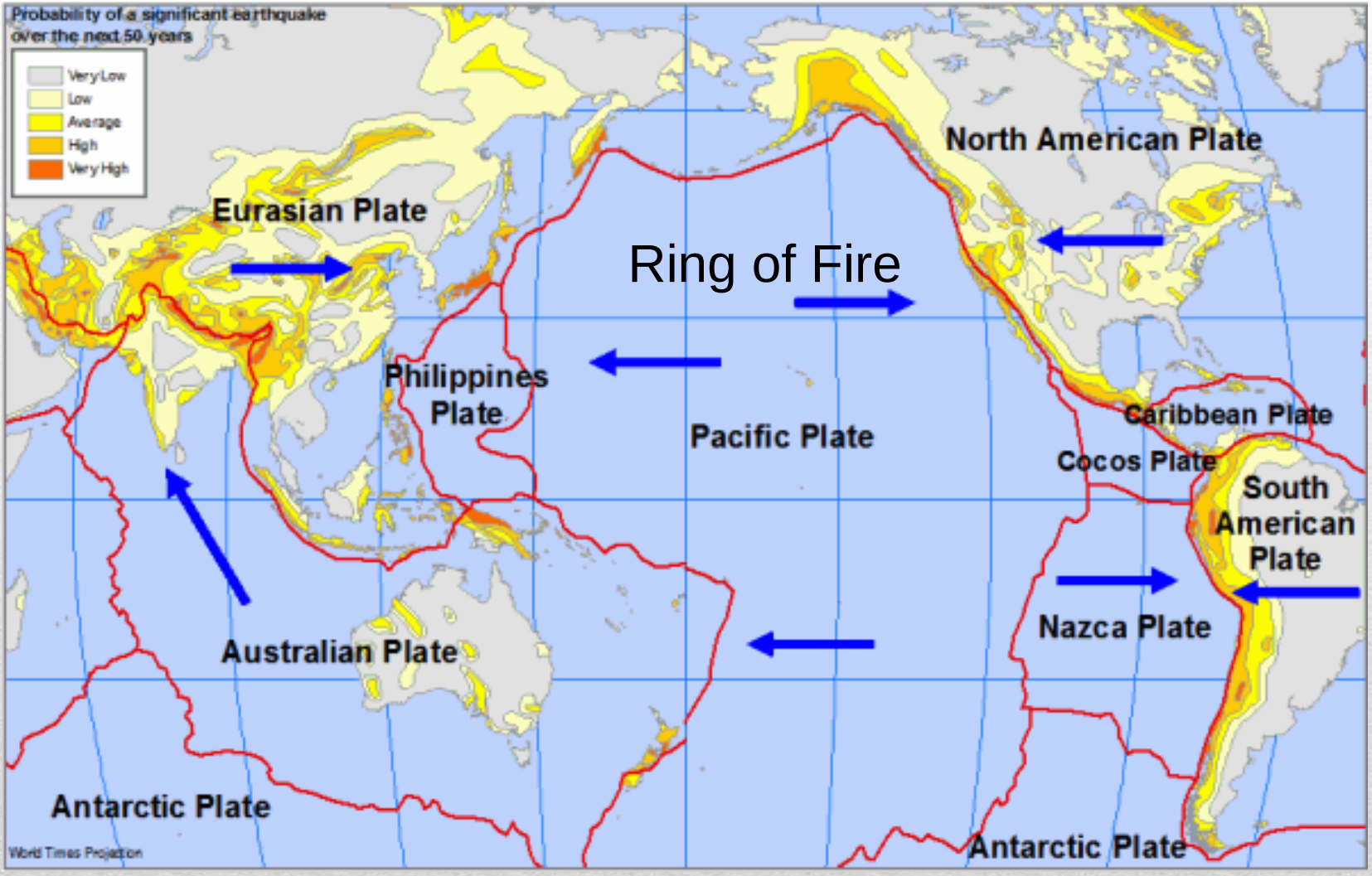

Yellowstone
Hawaii
Galapagos

Geographic Regions at Risk from Volcanoes

- Earthquakes, volcanoes are related to tectonics and most occur around the Ring of Fire
- Hot spots or riffs found in the Pacific Ocean or at mid-ocean ridges
- Areas along the Pacific Coast, in Yellowstone and in isolated areas of the Southwest are at risk

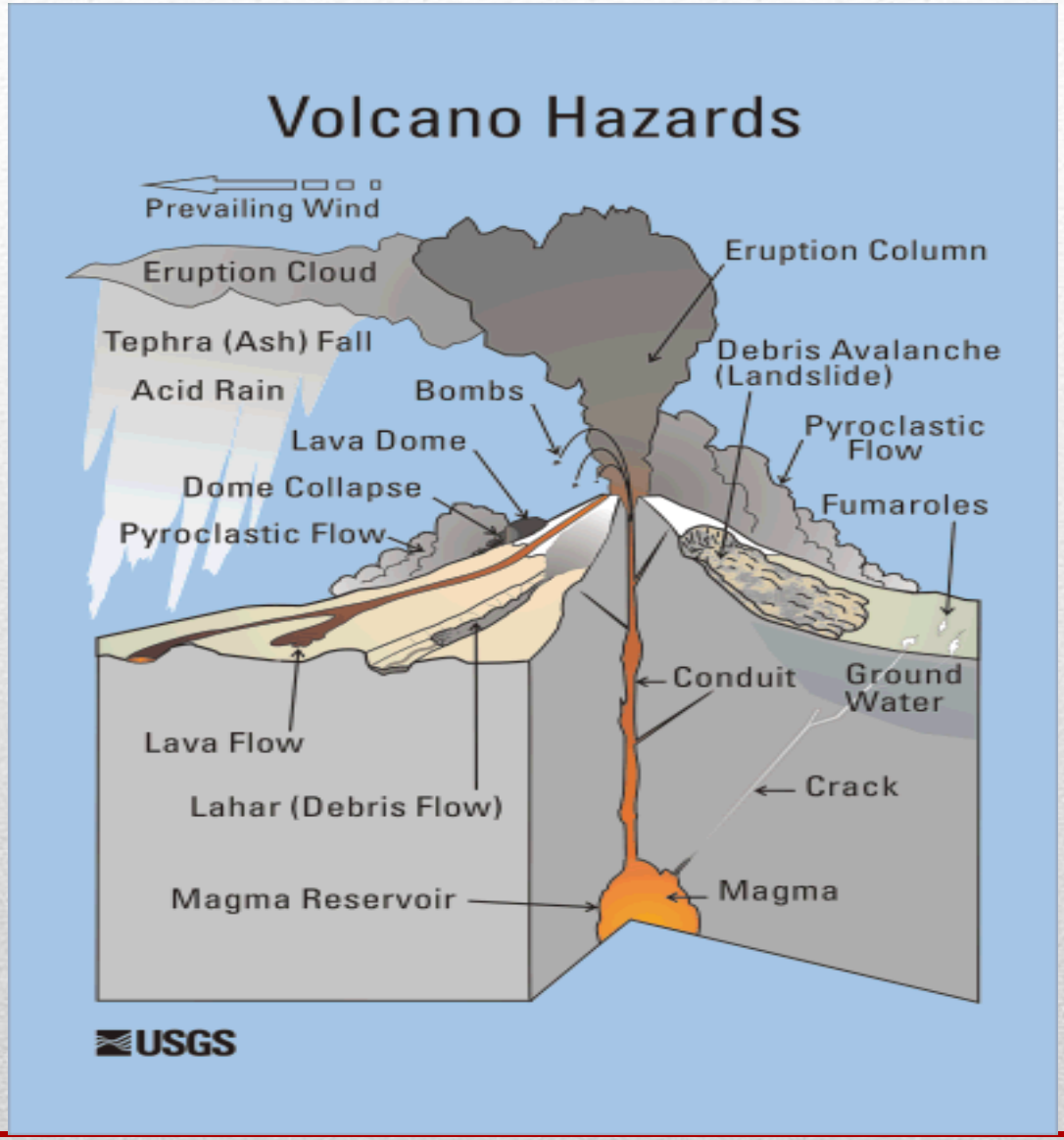
Pacific Ring of Fire

- **Ring of active volcanoes surrounding the Pacific Ocean**
- **Found primarily along the subduction zones of the Pacific Basin plate boundaries**
- **Some segments along the transform and divergent plate boundaries**


Probability of a significant earthquake over the next 50 years
Very Low
Low
Average
High
Very High
Eurasian Plate
North American Plate
Ring of Fire
Philippines Plate
Pacific Plate
Caribbean Plate
Cocos Plate
South American Plate
Nazca Plate
Australian Plate
Antarctic Plate
Antarctic Plate
World Times Projection

Volcanic Hazards

- **Lava flows**
  - Rarely cause loss of life, but cause lots of damage
- **Proclastic flows**
  - Collapse of the lava dome or explosive eruption causes high speed avalanche of searing hot gases, ash, and rock fragments
- **Volcanic Ash**
  - Covers vegetation, contaminates surface water, damages buildings as ash piles on roofs, creates health hazards, and can cause flame outs in airplane engines
- **Volcanic Gases**
  - Emissions of noxious gases such as carbon dioxide, sulfur dioxide, hydrogen sulfide, and fluorine
- **Eruption Column and Clouds**
  - Changes the air quality and weather
- **Volcanic Mudflows (Lahars)**
  - A loose mantle of ash and proclastic flow on the sides of a volcano slides during a heavy rain storm.



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Linkages between Volcanoes and other Natural Hazards

- Volcanoes are linked to their physical environment as well as to several other natural hazards
  - Fires
  - Earthquakes
  - Landslides
  - A change in global climates

Natural Service Function of Volcanoes

- Volcanic Activity Serve in Natural Functions by
  - **Volcanic Soils**
    - Provides excellent growth medium for vegetation
  - **Geothermal Power**
    - Used to create power for nearby urban areas
  - **Mineral Resources**
    - Host and source for mineral resources
  - **Recreation**
    - Creates health spas and hot spots
  - **Creation of New Land**
    - Responsible for new land during the eruption

Human Interaction with Volcanoes

- Unlike earthquakes, volcanoes do not lend themselves to human tinkering, little can be done to stop them

- Minimizing the Volcanic Hazards
  - Forecasting – Unable to forecast but certain information can be obtained that can help
    - Monitoring seismic activity
    - Monitoring thermal, magnetic, and hydrologic conditions
    - Monitoring the land surface to detect tilting or swelling of the volcano
    - Monitoring volcanic gas emissions
    - Studying the geologic history of a particular volcano or volcanic center

Minimizing the Volcanic Hazards

- Monitoring **seismic activity**
  - Small earthquakes around the area of a volcano
- Monitoring **thermal, magnetic, and hydrologic conditions**
  - Magma accumulation can heat rock or water, change magnetic stimulus or change water temperature
- Monitoring the **land surface** to detect tilting or swelling of the volcano
  - The change in the land surface around a volcano can indicate change in the volcano
- Monitoring volcanic **gas emissions**
  - A volcano getting ready to erupt can have a change in gas emissions
- Studying the **geologic history** of a particular volcano or volcanic center
  - Understanding the geologic history of the volcano can help in knowing if it is going to erupt

Volcanic Alert or Warning

- When should the public be alerted to the emanate danger of a volcanic eruption
  - Using a system of ground-based levels and aviation-based color code levels, the public can be alerted to a volcanic eruption
  - Developed by USGS, used by 5 volcanic observatories
  - Each component has four levels for monitoring
    - Usually the alerts for the volcanoes and eruptions will be the save for both levels (ground and aviation)
  - But for some the ground alert maybe more than the aviation or reversed, depending the kind of volcano

The USGS Alert-Notification System for Volcanic Activity

Volcano Alert Levels Used by USGS Volcano Observatories

Alert Levels are intended to inform people on the ground about a volcano's status and are issued in conjunction with the Aviation Color Code. Notifications are issued for both increasing and decreasing volcanic activity and are accompanied by text with details (as known) about the nature of the unrest or eruption and about potential or current hazards and likely outcomes.

Term	Description
NORMAL	Volcano is in typical background, noneruptive state *or, after a change from a higher level,* volcanic activity has ceased and volcano has returned to noneruptive background state.
ADVISORY	Volcano is exhibiting signs of elevated unrest above known background level *or, after a change from a higher level,* volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
WATCH	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, **OR** eruption is underway but poses limited hazards.
WARNING	Hazardous eruption is imminent, underway, or suspected.

Aviation Color Code Used by USGS Volcano Observatories

Color codes, which are in accordance with recommended International Civil Aviation Organization (ICAO) procedures, are intended to inform the aviation sector about a volcano's status and are issued in conjunction with an Alert Level. Notifications are issued for both increasing and decreasing volcanic activity and are accompanied by text with details (as known) about the nature of the unrest or eruption, especially in regard to ash-plume information and likely outcomes.

Color	Description
GREEN	Volcano is in typical background, noneruptive state *or, after a change from a higher level,* volcanic activity has ceased and volcano has returned to noneruptive background state.
YELLOW	Volcano is exhibiting signs of elevated unrest above known background level *or, after a change from a higher level,* volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
ORANGE	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, **OR** eruption is underway with no or minor volcanic-ash emissions [ash-plume height specified, if possible].
RED	Eruption is imminent with significant emission of volcanic ash into the atmosphere likely **OR** eruption is underway or suspected with significant emission of volcanic ash into the atmosphere [ash-plume height specified, if possible].

Perception of and Adjustment to the Volcanic Hazard

- Information concerning how people perceive a volcanic hazard is limited
- People live near volcanoes for a variety of reasons
  - They were born there and in the case of some islands, all land is volcanic
  - The land is fertile and good for farming
  - People are optimistic and believe an eruption is unlikely
  - They cannot choose where they live, they may be limited by economics
- The best way to limit concern about living near a volcano would be to better understand the what needs to be done in a **volcanic crisis**

Perception of and Adjustment to the Volcanic Hazard

- **Adjustments to Volcanic Hazards**
  - Major adjustment of understand evacuation
  - People need to understand the hazards and when told to evacuate
  - Some places are offering rewards to relocate
- **Attempts to control lava flows**
  - There have been some attempts to regulate the flow of lava
    - One way is called **hydraulic chilling** where the flow of lava is controlled
    - For this to happen 3 things have to be available
      - Slow movement of lava
      - Available transportation and roads to move the machinery on
      - Water is ready available